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Title of the Invention: GaN Vertical Cavity Surface Emitting Laser

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Abstract of the Invention

The subject invention relates to a GaN vertical cavity surface emitting laser wherein a current confinement layer is composed of aluminum nitride oxide and Bragg Reflector is used as a reflecting layer for a laser diode. The vertical cavity surface emitting laser comprises: a substrate, a first reflecting layer formed on one side of the substrate, a buffer layer formed on the other side of said substrate, an N-type GaN layer formed on said buffer layer (where a first electrode is formed on said N-type GaN layer), a first current confinement layer formed on said N-type GaN layer, a first cladding layer formed on said first current confinement layer, an active layer formed on said first cladding layer, a second cladding layer formed on said active layer, a second current confinement layer formed on said second cladding layer, a P-type GaN layer formed on said second current confinement layer (where a second electrode is formed on said P-type GaN layer), and a second reflecting layer formed on said P-type GaN layer. Furthermore, cladding layers may be respectively formed between said first current confinement layer and said N-type GaN layer and between said second current confinement layer and said P-type GaN layer.

Description of the Invention

The subject invention relates to a GaN vertical cavity surface emitting laser. The subject invention particularly relates to a GaN vertical cavity surface emitting laser including a confinement layer of an aluminum nitride oxide and a dielectric reflector.

Given that laser diodes having a short-wavelength blue light are increasingly in demand, nitrides of group III-V semiconductors are most noticeable among materials for use in preparing such laser diodes. Recently, S. Nakamura et al. presented the use of a sapphire substrate (C-face) to manufacture a laser diode having an InGaN quantum well structure. In such manner, reactive ion etching (RIE) is used to form a reflector cavity surface. Such laser can be operated in a manner of continuous wavelength (CW) at room temperature. Moreover, similar structures also can be formed on a sapphire (A-face) and spinel substrates. The crystal face having a surface property is formed on the cleavage surface of each layer deposed along the R-face direction of the sapphire substrate (A-face).

However, there are some drawbacks present in the above lasers. First, for the laser operation at a low critical current, a current confinement layer is not provided to control the current. Moreover, it is not easy to obtain a smooth reflector crystal face. Therefore, the conventional technology for manufacturing laser diodes is difficult in processing. Also, the properties of the elements are not satisfying.

In view of the above, the subject invention provides a GaN vertical cavity surface emitting laser (VCSEL) having a confinement layer of an aluminum nitride oxide and a dielectric reflector. The subject invention utilizes an aluminum nitride oxide as the current confinement layer. Therefore, the GaN vertical cavity surface emitting laser of the subject invention can be operated in continuous wavelength at room temperature, and thus the drawbacks of known processes and structures are overcome.

Moreover, the subject invention utilizes a dielectric reflector, e.g., distributed Bragg reflector to adjust the reflective index by controlling the differences in reflective index of the dielectric materials composing the reflector. Therefore, it is unnecessary to particularly manufacture a smooth reflecting crystal face.

To further disclose the process, structure, and advantage of the subject invention, preferred embodiments are described according to the drawings as follows:

Figures 1a to 1f show the cross-section surfaces of the scheme for manufacturing one preferred embodiment of the GaN vertical cavity surface emitting lasers of the subject invention.

Since it is unnecessary to split the crystal face, the subject invention provides a vertical cavity surface emitting laser structure to produce a GaN/InGaN blue light or green light laser. In an optical system, it is very advantageous to use a vertical cavity surface emitting laser as a light source because it can be collected in an array, effectively coupled into optical fibers, and easily used in a wafer test.

Please refer to Figures 1a to 1f. The production process of the subject invention mainly comprises the following steps: (1) forming a buffer layer 14 and an N-type GaN layer 16 on one side of a substrate 12 in sequence by using MOCVD or MBE technology (as shown in Figure 1a); (2) forming on said N-type GaN layer 16 a first cladding layer 18, a first aluminum nitride layer 20, a second cladding layer 21, an active layer 22, a third cladding layer 24, a second aluminum nitride layer 26, a fourth cladding layer 27, and a P-type GaN layer 28 in sequence (as shown in Figure 1b); (3) etching the layers formed on said substrate 12 until said N-type GaN layer 16 appears, thereby forming a first square or circular flat thereon by using dry-etching technology, wherein said flat has a width or diameter of about 60 to 100 μm, and then oxidizing the exposed aluminum nitride layers to form a first aluminum nitride oxide current confinement layer 20a and a second aluminum nitride oxide current confinement layer 26a, respectively (as shown in Figure 1c); (4) removing partial substrate by using grinding and polishing technology, thereby forming a smooth surface on the other side of said substrate 12, using silicon nitride (SiN_x) as a mask to protect said aluminum nitride oxide current confinement layers 20a and 26a, followed by depositing a dielectric material 32a, 32b and 10a, 10b (e.g., HfO_2/SiO_2, TiO_2/SiO_2, or SiN_x/SiO_2) on said P-type GaN layer 28 and the other side of said substrate 12 by using sputtering, vapor deposition, or ion-beam deposition technology, thereby forming a second reflecting layer 32 and a first reflecting layer 10, respectively (as shown in Figure 1d);

(5) etching said second reflecting layer 32 to form a square or circular flat having a size of about 20 to 30 μm (as shown in Figure 1e); and (6) forming electrodes 34 and 30 on said N-type GaN 16 and said P-type GaN 28, respectively (as shown in Figure 1f).

According to the above production procedure (see Figure 1f), the GaN vertical cavity surface emitting laser of the subject invention comprises: a substrate 12, a first reflecting layer 10 formed on one side of the substrate 12, a buffer layer 14 formed on the other side of said substrate 12, an N-type GaN layer 16 formed on said buffer layer 14 (where a first electrode 34 is formed on said N-type GaN layer 16), a first cladding layer 18 formed on said N-type GaN layer 16, a first current confinement layer 20 formed on said first cladding layer 18 (wherein said first current confinement layer 20 forms the one having pores 20a), a second cladding layer 21 formed on said first current confinement layer 20, an active layer 22 formed on said second cladding layer 21, a third cladding layer 24 formed on said active layer 22, a second current confinement layer 26a formed on said third cladding layer 24, a fourth cladding layer 27 formed on said second current confinement layer 26a, a P-type GaN layer 28 formed on said fourth cladding layer 27 (where a second electrode 30 is formed on said P-type GaN layer 28), and a second reflecting layer 32 formed on said P-type GaN layer 28.

Said first reflecting layer and said second reflecting layer are Bragg reflecting layers. Said first reflecting layer 10 is composed of the dielectric materials 10a and 10b having different reflective indexes. Said second reflecting layer 32 is composed of the dielectric materials 32a and 32b having different reflective indexes. Said current confinement layers can be aluminum nitride oxide or AlGaN having a high content of aluminum. Said substrate can be a sapphire or spinel.

In the vertical cavity surface emitting laser structure, a distributed Bragg reflector can be positioned on the upper and lower sides of the active region. The dielectric materials, such as HfO_2/SiO_2, TiO_2/SiO_2, or SiN_x/SiO_2 can be used in preparing the distributed Bragg reflector. The optical thickness of each dielectric material is 1/4 the wavelength of the emission wavelength. The materials can be cross-deposited by

using a sputtering, vapor deposition, or ion-beam deposition manner to form a Bragg reflector. The difference between the reflective index of TiO_2 (about 2.3) and that of SiO_2 (about 1.46) is greater than that between HfO_2 (about 2) and SiO_2. However, the ultraviolet cut-off frequency of HfO_2 is higher.

Moreover, in the vertical cavity surface emitting laser structure, the basic laser structure is a double heterojunction structure of InGAN/GaN multiple quantum wells formed by using metal oxide chemical vapor deposition (MOCVD) or molecule-beam phase epitaxy (MBE). In the double heterojunction structure of multiple quantum wells, a P-type aluminum nitride layer and an N-type aluminum nitride layer, both of which have a thickness of about 1000 to 3000 Å, are formed on the upper and lower sides of the active region, respectively.

The oxidation of said aluminum nitride layer is conducted in an oxidizer under a temperature of about 400 to 600 ℃, or in nitrogen air which has passed water, wherein the temperature of water is about 90 to 95 ℃. The oxidation time is determined based on the pore size, which is between 3 and 15 μm.

Moreover, said first and fourth cladding layers can be removed from the structure of the above embodiment to obtain a simplified GaN vertical cavity surface emitting laser.

Given the above, it can be known that the subject invention features the selection of an aluminum nitride oxide as a current confinement layer and the use of Bragg reflector as a reflecting layer necessary to a laser diode in order to replace the demand of a smooth reflecting surface, thereby reducing the production difficulty. Therefore, the process of the subject invention can be used in any laser diodes of the GaN group.

Claims

1. A GaN vertical cavity surface emitting laser, comprising:

a first reflecting layer formed on one side of a substrate;

a buffer layer formed on the other side of said substrate;

an N-type GaN layer formed on said buffer layer, where a first electrode is formed on said N-GaN layer;

a first current confinement layer formed on said N-type GaN layer;

a first cladding layer formed on said first current confinement layer;

an active layer formed on said first cladding layer;

a second cladding layer formed on said active layer;

a second current confinement layer formed on said second cladding layer;

a P-type GaN layer formed on said second current confinement layer, where a second electrode is formed on said P-type GaN layer; and

a second reflecting layer formed on said P-type GaN layer.

2. A GaN vertical cavity surface emitting laser, comprising

a first reflecting layer formed on one side of a substrate;

a buffer layer formed on the other side of said substrate;

an N-type GaN layer formed on said buffer layer, where a first electrode is formed on said N-type GaN layer;

a first cladding layer formed on said N-type GaN layer;

a first current confinement layer formed on said first cladding layer;

a second cladding layer formed on said first current confinement layer;

an active layer formed on said second cladding layer;

a third cladding layer formed on said active layer;

a second current confinement layer formed on said third cladding layer;

a fourth cladding layer formed on said second current confinement layer;

a P-type GaN layer formed on said fourth cladding layer, where a second electrode is formed on said P-type GaN layer; and

a second reflecting layer formed on said P-type GaN layer.

3. The GaN vertical cavity surface emitting laser of Claim 1 or 2, wherein said first reflecting layer and said second reflecting layer are Bragg reflecting layers.

4. The GaN vertical cavity surface emitting laser of Claim 1 or 2, wherein said current confinement layers can be aluminum nitride oxide or AlGaN having a high content of aluminum.

5. The GaN vertical cavity surface emitting laser of Claim 1 or 2, wherein said substrate can be a sapphire or spinel.

6. The GaN vertical cavity surface emitting laser of Claim 3, wherein said Bragg reflecting layer can be HfO_2/SiO_2, TiO_2/SiO_2, or SiN_x/SiO_2 structure, and the optical thickness of each material is 1/4 the wavelength of the emission wavelength.

7. A process for manufacturing a GaN vertical cavity surface emitting laser, comprising the steps of:

forming a buffer layer and an N-type GaN layer on one side of a substrate in sequence;

forming on said N-type GaN layer a first aluminum nitride layer, a first cladding layer, an active layer, a second cladding layer, a second aluminum nitride layer and a P-type GaN layer in sequence;

etching the layers formed on said substrate until said N-type GaN layer appears, thereby forming a first square or circular flat thereon;

oxidizing the exposed aluminum nitride layers to form a first aluminum nitride oxide current confinement layer and a second aluminum nitride oxide current confinement layer, respectively;

removing partial substrate, thereby forming a smooth surface on the other side of said substrate;

using silicon nitride as a mask to protect said aluminum nitride oxide current confinement layers, followed by depositing a dielectric material on said P-type GaN layer and the other side of said substrate, thereby forming a second

reflecting layer and a first reflecting layer, respectively; and

etching said second reflecting layer to form a second square or circular flat, followed by forming a first electrode and a second electrode on said N-type GaN and said P-GaN, respectively.

8. A process for manufacturing a GaN vertical cavity surface emitting laser, comprising the steps of:

forming a buffer layer and an N-type GaN layer on one side of a substrate in sequence;

forming on said N-type GaN layer a first cladding layer, a first aluminum nitride layer, a second cladding layer, an active layer, a third cladding layer, a second aluminum nitride layer, a fourth cladding layer, and a P-type GaN layer in sequence;

etching the layers formed on said substrate until said N-type GaN layer appears, thereby forming a first square or circular flat thereon;

oxidizing the exposed aluminum nitride layers to form a first aluminum nitride oxide current confinement layer and a second aluminum nitride oxide current confinement layer, respectively;

removing partial substrate, thereby forming a smooth surface on the other side of said substrate;

using silicon nitride as a mask to protect said aluminum nitride oxide current confinement layers, followed by depositing a dielectric material on said P-type GaN layer and the other side of said substrate, thereby forming a second reflecting layer and a first reflecting layer, respectively; and

etching said second reflecting layer to form a second square or circular flat, followed by forming a first electrode and a second electrode on said N-type GaN and said P-GaN, respectively.

9. The process of Claim 7 or 8, wherein the formation of each layer on the substrate is conducted by using ion oxide chemical vapor deposition or molecule-beam phase epitaxy.

10. The process of Claim 7 or 8, wherein AlGaN having a high content of aluminum can replace said first aluminum nitride layer and said second aluminum nitride layer.

11. The process of Claim 7 or 8, wherein said first flat has a width or diameter of about 60 to 100 μm.

12. The process of Claim 7 or 8, wherein said second flat has a width or diameter of about 20 to 30 μm.

13. The process of Claim 7 or 8, wherein the oxidization of said aluminum nitride is conducted in an oxidizer under a temperature of about 400 to 600℃ or in a nitrogen air which has passed water, wherein the temperature of said water is about 90 to 95℃.

14. The process of Claim 7 or 8, wherein the oxidation time of said aluminum nitride layer is determined based on the pore size, which is between 3 and 15 μm.

15. The process of Claim 7 or 8, wherein the removal of partial substrate is conducted by using a grinding or polishing manner, thereby obtaining a smooth and stainless surface.

16. The process of Claim 7 or 8, wherein said reflecting layers can be Bragg reflecting layers, wherein the Bragg reflector is prepared by using sputtering, vapor deposition, or ion-beam deposition to cross-deposit two dielectric layers having different reflective indexes, where each layer has an optical thickness of 1/4 the wavelength.

17. The process of Claim 16, wherein HfO_2/SiO_2, TiO_2/SiO_2, or SiN_x/SiO_2 can be used as a material for preparing the Bragg reflector.

18. The GaN vertical cavity surface emitting laser of Claim 1, wherein said first aluminum nitride layer can be removed, thereby simplifying the laser diode structure.

19. The GaN vertical cavity surface emitting laser of Claim 2, wherein said first aluminum nitride layer and said first cladding layer can be removed, thereby simplifying the laser diode structure.

20. The process of Claim 7, wherein said first aluminum nitride layer can be removed, thereby simplifying the laser diode structure.

21. The process of Claim 8, wherein said first aluminum nitride layer and said first cladding layer can be removed, thereby simplifying the laser diode structure.

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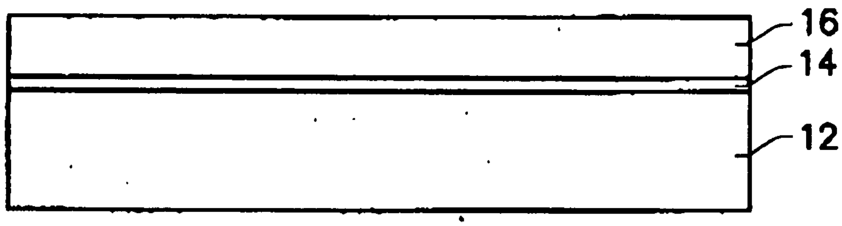

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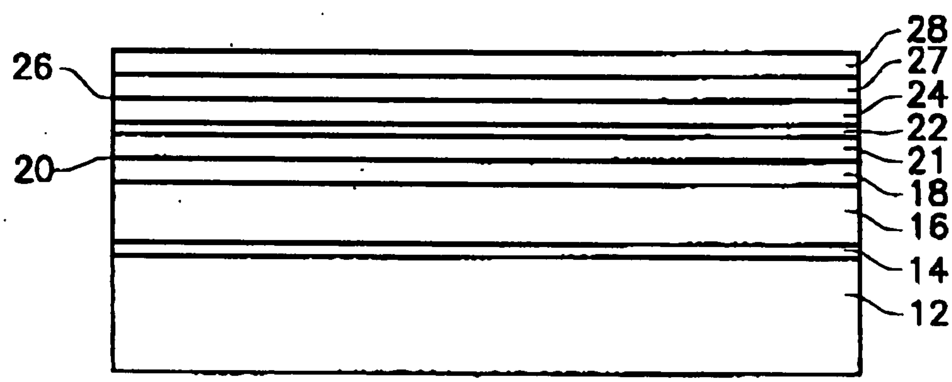

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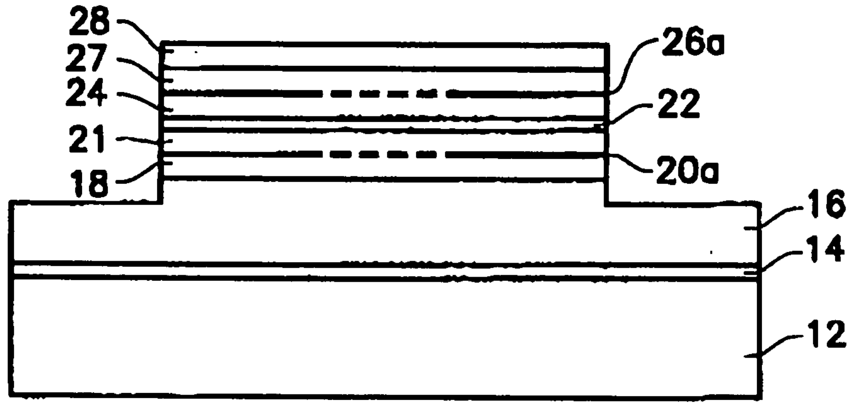

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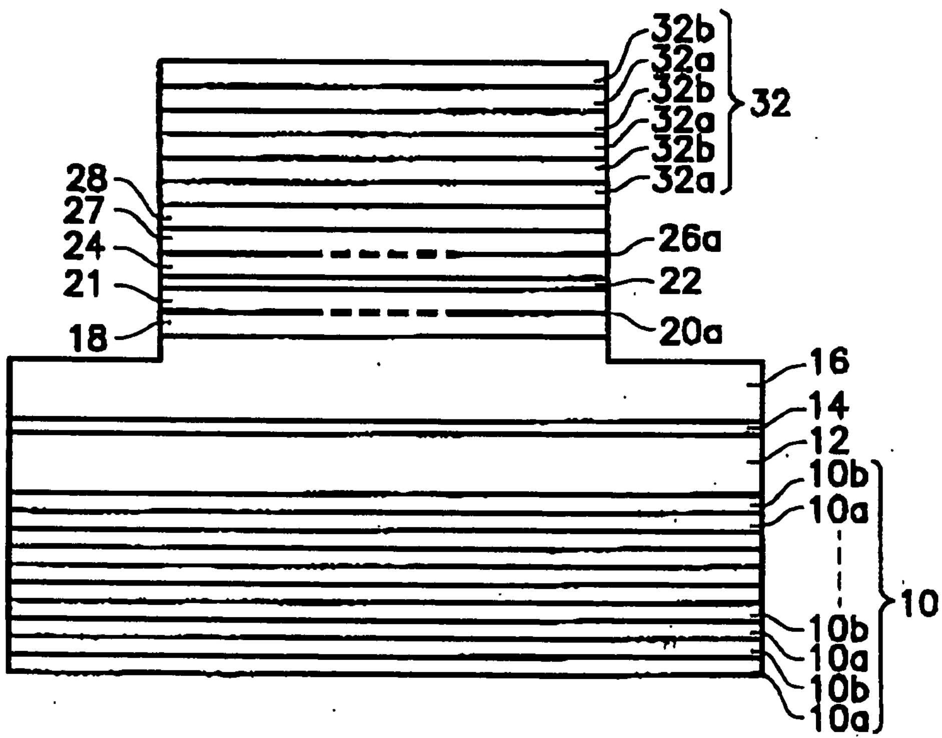

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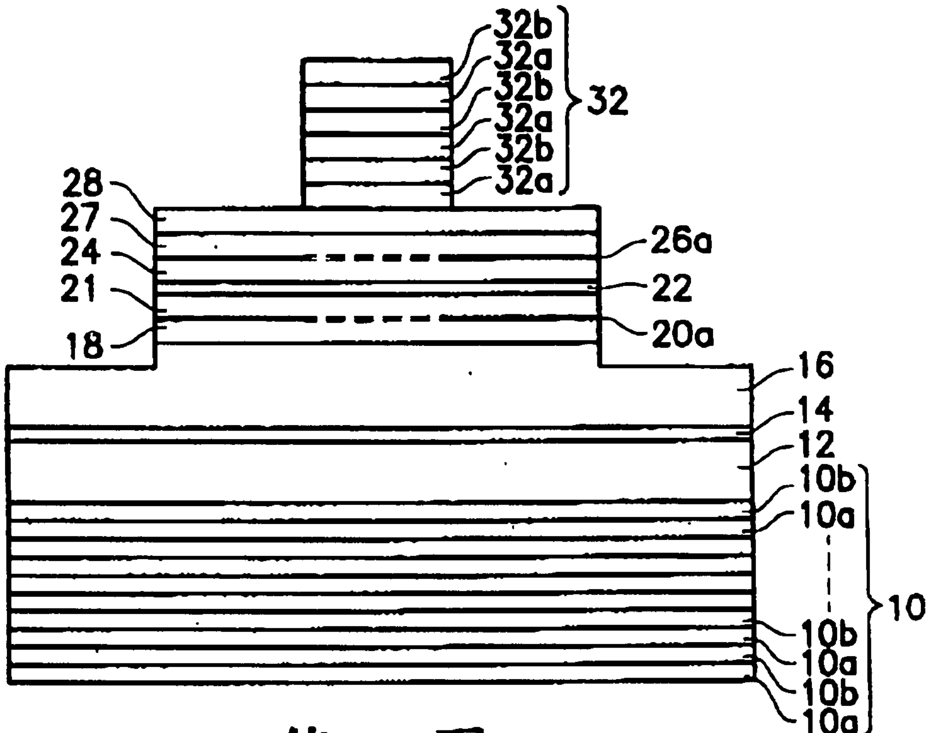
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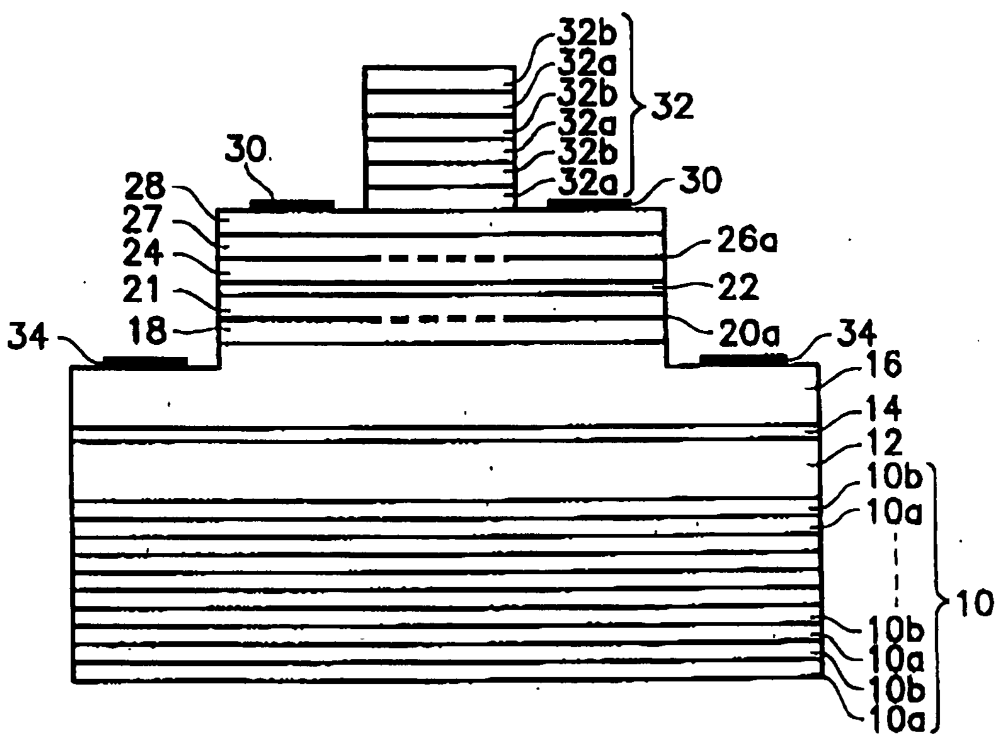
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第 1f 圖